VOLUME XXVII NUMBER 6 WHOLE NUMBER 225

THE JOURNAL

OF

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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PUBLISHED MONTHLY
(Ten numbers per year)

July-August 1933

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL

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THE STUDY OF THE SOLAR CORONA WITHOUT AN ECLIPSE

By Bernard Lyot

Astronomer at the Observatory of Meudon

Translated by Roy K. Marshall
(With Plate V)

Translator's Note

Dr. Lyot is a young man, having received his doctor's degree only in 1929. His thesis for this degree had for its subject "Studies in the Polarization of the Light of the Planets and of some Terrestrial Materials". This study was the result of the use of a polarimeter especially designed by Dr. Lyot. Its sensitivity is ten times as great as that of any similar existing instrument; it is capable of detecting polarized light when it exists as only one thousandth of the total amount of light. The complete thesis, 161 pages long, is to be found in Vol. VIII of the Annals of the Observatory of Meudon, and is considered by the faculty at the Sorbonne to be a most excellent piece of research. Since completion of this study, Dr. Lyot has been engaged in the further use of the polarimeter which he designed, and in other researches connected with light. The present work was first started in the summer of 1930, and was followed up with more extensive plans and preparations in the following summer. At the meeting of la Société Astronomique de France, Jan. 7, 1931, he gave a preliminary report of the results of his work. As a result, he was awarded the Prix Janssen, established in 1896 by the astronomer whose name it bears, for 1932. Among others who have held this honour are Flammarion, Lowell, Barnard, E. C. and W. H. Pickering, Hale, Michelson, Ritchey, Adams, Eddington, and Einstein, so Dr. Lyot travels in good company.

His work on the solar corona was conducted at the Observatory of Pic du Midi, in a wild and isolated mountainous region in southern France. The observatory itself (described in *L'Astronomie*, *42*, 209 (1928)) is situated almost at the summit of the mountain, on a platform constructed for it. Construction work was very difficult, inasmuch as the open season on the

peak was only three months long; during the rest of the year the snow is heavy, and the peak inaccessible except by climbing on foot. The principal instruments are mounted together, in a yoke, as at Mount Wilson, and comprise a refractor of 20 centimetres and a reflector of 50 centimetres aperture. The focal lengths are 6 metres. The tube is a rectangular parallelopiped, and is equipped with clamps and other devices so that auxiliary apparatus may readily be attached. Meteorological apparatus forms a part of the equipment of the observatory, and on the actual summit of the peak, a little distance away, a geodetic landmark is located. Further description of the advantages of the situation will be left to Dr. Lyot himself, but the translator urges that all who can will look at the illustration of the observatory, printed in *L'Astronomie, 42,* facing page 216; it is to be hoped that no one who is a victim of somnambulism will ever go there to work, for he would be likely to awaken on his way to the bottom of the valley, a fall of about 9,000 feet!

The work of Dr. Lyot so far has been reported in *l'Astronomie* in two papers; the first appeared in Vol. *45,* p. 248 (1931) and discussed the results of the first summer, that of 1930; the second appeared just a year later (Vol. *46,* p. 272, 1932), and reported the much more extensive results of the second summer of work. Dr. Lyot and Mme. G. Camille Flammarion (representing the editors of the French journal) have very graciously given the translator permission to reproduce the two articles; further, Dr. Lyot sent copies of the original prints, from which most of the illustrations in the translation have been made. To him and to the editors of *l'Astronomie* I take this opportunity to express my great appreciation of the courtesy and honour they have done me. The new readers who will be garnered through the medium of this translation will have to judge for themselves whether they believe the great step has been made; surely it will be made sometime, as was the similar step with reference to the prominences and reversing layer, by Lockyer and one of Dr. Lyot's countrymen, Jansen. Dr. Lyot's results look convincing, and it is to be hoped that he has opened up a new way to study the elusive corona. But what a blow it will be to globe-trotting, eclipse-hunting astronomers!

R. K. M.

First Paper

FOR the astrophysicists, the solar corona constitutes an especially interesting object of study; it offers a great many problems, of which the greater part are a long way from being solved. Its form, for example, varies periodically according to the general solar activity, but we are ignorant of the causes of these variations and of the nature of the bond which connects them to the variations of the chromosphere and the spots. Its light is polarized as would be that of a gas illuminated by reflection from the sun, but, contrary to what one might expect, its spectrum does not in general show the solar lines. Its spectrum contains, on the contrary, bright lines, of which the origin is yet unknown.

Unfortunately, while the spots and faculae are visible at all

times with the help of a simple telescope, and the chromosphere and prominences are revealed to us every day by the spectroheliograph, the corona, on the contrary, has not been able to be observed, up to this time, except during total eclipses, that is to say, on the average, during one or two minutes per year. Its observation necessitates distant and expensive expeditions; it cannot be done with large instruments, the transportation and installation of which, in uncultivated regions, would be very difficult.

Moreover, long eclipses are very rare, the longest never exceeding 7 minutes. This short duration often makes it necessary to forego direct measures and to replace them with photographic methods. Moreover, because of the faintness of the corona, the long exposures which would often be necessary are forbidden, for example, for photographing its spectrum with very high dispersion or for obtaining monochromatic images by means of the spectroheliograph.

In view, therefore, of such unfavourable circumstances, astronomers and physicists during a half-century have sought a method permitting the study of the corona without an eclipse. The first attempts along this line were made in 1878; it would be very tedious to mention all those which have been made since that date, usually by the foremost observers. Most of them simply photographed the region of the sky where the sun was, either directly or by filtering the light through coloured screens placed against the plate. A metal disc, a little larger than the image of the sun, covered the centre of the plate, in order to stop the direct solar rays and to avoid in this way a photographic halo. Only the blue and violet radiations were used at first, but the progress in the art of sensitizing photographic plates finally permitted the use of the red rays and those of the near infra-red, which, because of their longer wavelengths, are much less strongly diffused by our atmosphere. The photographs obtained in this way, sometimes at stations at high altitudes or where the air is very pure, show, in general, halos of which certain ones closely resemble the corona. Other plates as well were obtained by Hale and Deslandres, with the aid of the spectroheliograph, by isolating the light of the blackest lines of the solar spectrum. The light of the sky, which shows these absorption

lines, should therefore appear fainter than that of the corona which, in general, does not show them. This procedure, as well, gave images of coronal appearance.

Unfortunately, none of these halos which have been photographed can be attributed to the corona. Indeed, the exposure times with which they were obtained are tens and even hundreds of times too short to permit the registration of the true corona during an eclipse! None of these pictures show the prominences, which ought to be much more intense than the corona. Finally, tests made during partial eclipses show coronas which extend over the moon. The moon's limb could not be photographed, except on the sun's disc, during eclipses of magnitude greater than 0.98, and which, therefore, were almost total.

Some attempts of another kind were made by Deslandres and Hale to reveal the infra-red radiation of the corona without an eclipse. This light was permitted to fall on a very sensitive heat-registering device, consisting of either a bolometer or an electric thermopile. These attempts gave no definite results, partly, without doubt, because the infra-red radiation of the corona is very feeble.

The causes of these failures have been investigated for a long time. Our atmosphere alone, from the very first, has been held responsible. Indeed, it diffuses a bright light which is sufficient to conceal that of the corona. However, if this atmosphere were perfectly pure, the sky would have all over the blue tint which we know it to have, its brightness would be very uniform, and its value, near the sun, would be only double that which it has 90 degrees away, at the same altitude, of course. Since the moon is easily visible by day, the lower portions of the corona, as bright as the full moon, should be observable without an eclipse, especially with the red and infra-red rays.

Although it is a beautiful phenomenon, the sun unfortunately appears to be surrounded by a white halo, more or less extended and diffuse, the inner portions of which are always more brilliant than the rest of the sky. This halo is very important because of the enormous brilliance of the sun, which amounts to about a million times that of our atmosphere. A few grains of dust between the observer and the sun suffice to produce it; they send out by diffrac-

tion a quantity of light equal to that which they receive from the sun, and this is concentrated in a direction near that of the incident rays. If the observer has a telescope, the diffusion by the glass still further strengthens this halo. These false coronas are superimposed on the true one, which they resemble in appearance, and hide it entirely. Nevertheless, if this halo is reduced to its minimum, it should be possible to distinguish the true corona because of the peculiar properties of its light—its polarization and its spectrum of bright lines.

That is what I tried to do during the months of July and August, 1930, at the observatory of Pic du Midi. The observatory there presents advantages for the study of the corona which are not found united elsewhere. It is easily accessible in summer. Its altitude is very great—2,860 metres (9,383 feet). By virtue of this fact, the observer has over his head no more than two-thirds of our atmosphere, while under his feet he has the dust of the lower levels and the strata of air most filled with miscellaneous vapours—in a word, the atmospheric slime. It is south of 43 degrees latitude, a fact which permits observation of the sun farther from the horizon for a longer time than at any other of the French observatories. Finally, it is possible to take advantage of a double telescope 6 metres long, the mounting of which is extremely rigid, and on which it is possible to mount with ease the apparatus for maintaining the setting on the sun.

I was able to take advantage of twenty-seven days of work at Pic du Midi, between July 9 and August 11, 1930. The sea of clouds generally spread out a few hundred metres below the level of the dome, while the sky often remained a perfect blue. It was possible to cover the sun with a screen held at a distance, without seeing any halo around it.

By virtue of these excellent conditions, I was able to analyze the polarization of the inner corona and to study two bright lines of its spectrum. The image of the sun was formed by an optical system which diffused very little light, falling on a metal disc which slightly exceeded the sun's image in size. The observer, protected by this screen, was able to examine directly the immediate neighbourhood of the sun, up to 30″ from its edge, without being blinded, at the same time using a low power eyepiece.

Under these conditions, the prominences were visible without the help of the spectroscope, and likewise without the interposition of any colour filter. They appeared to be of the rosy colour which they show at the time of eclipses. With a filter of red glass, they could be seen against a very dark sky, and their delicate details could be seen directly, in spite of the small aperture used (4 centimetres). It was easy to follow their contours up to within 30″ of the limb of the sun. In this manner I could observe the most remarkable changes in them; one, in position angle of about 127 degrees, on July 13 and 14, showed a very complex structure consisting of multiple arches; another, at about 310 degrees, appeared to be relatively quiet on July 26, but on July 27 it ascended quite rapidly, and, thinning out at the base, it detached itself from the sun's limb, afterwards reshaping its base. Its height exceeded a quarter of the diameter of the sun. A series of exposures made on August 11, on panchromatic plates through a thin red filter, shows a small but exceedingly bright prominence; its height, as measured at Meudon with the spectroheliograph, was about 70″.

In addition to the prominences, there was seen around the sun, in spite of the excellent atmospheric conditions, a light halo, due in part to diffusion and in part to the inner corona. In order to sort out the part due to the corona, I analyzed the light of the halo with the polarimeter and with the spectroscope.

The polarization of the corona was studied by means of the "fringe" polarimeter which I used to analyse the light of the planets This piece of apparatus, sensitive to a proportion of polarized light of only one in a thousand, can turn about the image of the sun, examining the sectors of the sky in the neighbourhood. A circle shows the position angle of the observed point, referred to the centre of the sun; fixed cross wires, mounted in the eyepiece, permit the evaluation of the distance of the point from the limb of the sun. All measures were made while the sun was more than 50 degrees above the horizon, and the following results were obtained: Farther than 7′ from the limb, the polarization of the sky was zero; it was the same as that of the white halos produced by dust and cirrus. Polarization commenced to appear at 6′ from the limb, it increased rapidly in the direction of the sun, and then remained nearly

constant, below 3′ from the limb. It was stronger, the more transparent the sky; on the other hand, the passage of clouds, however slight, rendered it insensible.

It can be concluded from the preceding that the polarization found did not originate in the atmosphere; a laboratory study of the instrument used showed that it was not instrumental. It is really the polarization of the corona which was observed, reduced at each point, however, by the ratio of the brightness of the corona to that of the field. The graphs here shown (Fig. 1), give the proportions of polarized light found in the various position angles at a constant distance of 80″ from the limb of the sun. The fact that they some-

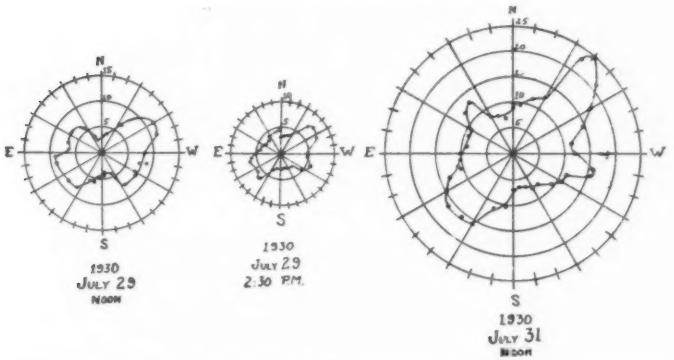

FIG. 1. Proportion of polarized light, expressed in thousandths, measured at 80″ from the limb of the sun, in various position angles.

times seemed not to close so perfectly is due to a slight variation in the transparency of the atmosphere in the course of the measures. Their sinuosities correspond, without doubt, to inequalities in the brightness of the inner corona, rather than to inequalities in the proportion of polarized light. They show two minima, practically coinciding with the line of the poles of the sun, and four maxima whose latitudes are between 20 and 50 degrees. The general form of these charts probably bears a close relation to that of the corona itself; it appears in good agreement with the actual activity of the sun, which has been decreasing during the past two years.

Spectral analysis, as well as the polarimeter, can be used at all times to show the inner corona. Without an eclipse, the continuous spectrum of the corona is entirely masked by that of the light of the sky, but the bright lines should remain observable on the luminous background, weakened by the dispersion, more or less accordingly as the conditions are most favourable.

I have performed the experiment of letting the image of the immediate neighbourhood of the sun fall on the slit of a direct vision spectroscope. On July 30 and the following days, there was to be seen among the dark lines of the solar spectrum due to the diffuse light, a bright line in the green, not far from the Fraunhofer E line. It was long and intense toward the northwest, where it could be followed as far as 4′ from the limb of the sun, fainter toward the southwest, and hardly observable at the north and south. This appearance, which persisted during the following days, is in good agreement with the polarization graphs of July 29 and 31. The line was strongest at the places where the polarization was strongest.

On August 3 and 4, when there was remarkable atmospheric transparency, I saw a second bright line in the red, between the *a* band and the C line. It was a little less intense, but almost as long as the green line, and it showed the same variations of length and strength about the sun.

On August 7, and particularly on the 10th, the green line appeared much more uniform, as shown by the illustration (Fig. 2). This plate was taken on August 10, at 10 a.m., on orthochromatic emulsion, with an exposure of 6 minutes. The slit was tangent to the limb of the sun, slightly cutting across the edge of the metal disc, and giving rise to the central black band. The disc was bordered by a narrow diffraction fringe, which produced the two lengthwise luminous bands. The bright line appears in the midst of the solar lines, a little to the right of the E line. On this same date, however, the red line was invisible, almost; it was barely distinguishable, weak and short, on two plates taken at the eastern limb, with a wide slit and exposures of 20 and 45 minutes, respectively.

Therefore the intensities of these two radiations vary differently;

the variations are considerable, not only from one year to the next, as eclipse observers have established, but even in the interval of only a few days.

The wave-length of the green line, obtained directly by comparison with the neighbouring solar lines, is 5303.2 ± 0.1 I.A. Measures of two plates of August 7 and 10, less accurate because of the low dispersion used (30 A/mm.), result in the values 5302.4 and 5302.5. Direct micrometric measures on the red line, difficult because of the faintness of the neighbouring groups of solar lines, gave 6374 I.A., while the two plates of August 10 give, respectively,

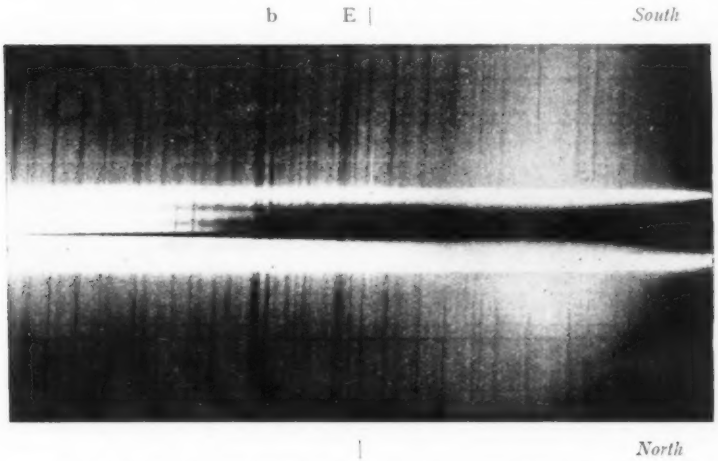

FIG. 2. The green line of the solar corona, photographed August 10, 1930, by Dr. B. Lyot. Slit tangent to east limb.

6370 and 6373.5 I.A. These two emission lines correspond very closely to the two strongest lines of the corona observed during eclipses, and for which wave-lengths of 5303.1 and 6374 have been determined.

These preliminary results show that hereafter it is possible to study the corona at all times, either by means of the polarimeter, in the light of the continuous spectrum, or by means of the spectrum, with the light of the emission lines. Hereafter an observer may

take advantage not only of the few minutes presented by total eclipses, but often of several hours consecutively. It will be possible to follow regularly the variations of the corona and its spectral lines, to study its rotation, and to discover the connections between them and the spots, faculae, and prominences. It will be possible, likewise, to attack the problems which necessitate long photographic exposures, such as the exact determination of the wave-lengths of the coronal lines, the study of radial velocities at each point of the corona, and the obtaining of monochromatic images by means of the spectroheliograph.

These advantages should not, however, cause us to abandon total eclipses of the sun, which will remain, for a long time yet, the only means of getting at the outer portions of the corona.

(*Concluded next issue.*)

THE EXPANSION OF THE UNIVERSE*

By J. S. Plaskett

I HAVE chosen this subject for us to consider tonight partly on account of the great interest attaching to any attempt to explore into the unseen and to reach out to, and if possible to peer a little beyond, the bounds of the universe. In addition, this subject is one of the most recent and the most amazing examples of the power of mathematical analysis to form models or concepts to predict properties, and to trace back the history of the Universe when only a practically infinitesimal portion of it can ever be observed. This present day conception of the expansion of the Universe is then, when the latter is only in very small part observable, an extrapolation and hence subject to the uncertainties and dangers well known to all scientists, of extrapolations. While its relativistic and mathematical exponents undoubtedly assign to it concrete and objective reality, a mere observational astronomer is perhaps a little more cautious and hesitates about whole hearted acceptance of anything so admittedly hypothetical, and so much outside the possibility of reaching any satisfactory mental concept of its structure.

It will be well, first of all, to clarify our ideas about the term Universe, as it has been sometimes loosely used in the past. For example, a few years ago when it was beginning to be realized that the spiral nebulae were probably stellar systems separate from the system or galaxy of which our sun is a member, it was not at all uncommon to hear them called "island universes" as if there could be more than one universe. The word "universe" implies a singleness, an inclusiveness, and a unity which must comprise the whole of Creation and which admits of no division or plurality. So far as matter is concerned all must be included in the Universe, there can be nothing outside or beyond.

Until about fifteen years ago when some of the consequences of the general theory of relativity, which was developed by Einstein about 1915, began to be envisaged, the question was in one sense relatively simple. The Universe was then simply considered as

*Presented to the Victoria Centre, March 10, 1933.

extending indefinitely in all directions without any boundary. It was equally impossible for the human mind to conceive either an end to space, or space without end, and one had to be content with the same uncertainty applied to space or the Universe as was already bound up with such terms as infinity or eternity.

About 1916 or 1917, however, the principles and equations of the general theory of relativity were extended to the ideas of space and the Universe, and two separate and distinct concepts of the organization of the "world," as it is generally called by relativists, were developed by Einstein and de Sitter, respectively, incorporating the new ideas of general relativity. The simple ideas of three-dimensional space, sometimes called Euclidean or flat space, this room being an example, which has the three dimensions, length, breadth and height, no longer hold. It is now necessary to add another dimension—time, the four dimensions altogether changing the properties of space and the Universe, and making it quite impossible for our three-dimensional minds to form any adequate mental picture or concept of four-dimensional space-time. Not only you and I, but even Einstein, de Sitter, Eddington or other mathematical physicists, are unable to form any satisfactory mental image of the nature and form of the space-time world, except as represented by the mathematical equations which are of little help even to mathematicians and only an aggravation to others.

The space-time Universe no longer extends indefinitely in all directions but it is finite, has a definite mass and volume, though stated to be unbounded. It has such paradoxical properties for example that a continuance in any direction whatever, if persisted in long enough, will bring you back to the starting point and that two parallel lines produced sufficiently far will eventually meet. Another property of the space-time Universe is that there will be images of the sun and stars on the other side of the world. According to the theory of relativity, this space-time Universe is homogeneous, is such that all positions in space are completely equivalent and there is no centre of gravity. This four-dimensional space is designated as curved, warped or reentrant space as distinct from the ordinary flat or Euclidean space of three dimensions which we can all readily visualize. According to relativity, the so-called radius of space, R, is constant while space itself is of uniform positive

curvature $1/R^2$ and has the finite volume, π^2R^3. If we take a sphere of the same radius R, the curvature of its surface is $1/R$, not $1/R^2$ and its volume is $\frac{4}{3}\pi R^3$, only about $\frac{3}{7}$ of the volume of space-time.

As stated previously, and as now seems evident from these curious properties, it is quite impossible for our three-dimensional minds to visualize this peculiar space-time world. A few months ago, however, an article appeared in the *Scientific American* which claimed to make models of four-dimensional curved space and though they do not provide us with a full picture, as the fourth dimension still eludes us, they do give us at least a partial idea of how a produced line will eventually return to its starting point and parallel lines will meet in curved space. The method consists, as I shall now show you, of folding the ends of a band of paper back on themselves with one turned through 180°. This is in a sense only two-dimensional but if you make the band thicker and thicker you may eventually gain some idea of space-time. You see at once that parallel lines meet and that a line produced far enough returns to the starting point. If I divide the paper by scissors I get something like reentrant space and by using our imaginations we can see the vast difference between this and ordinary three-dimensional space like a sphere.

Before describing the two kinds of space-time world developed by Einstein and de Sitter about fifteen years ago, I should warn you to accept all these concepts with some reservations and to remember that these models of the Universe are highly abstract, simplified and idealized, as indeed they have to be to treat them with the mathematics available. Let me quote from de Sitter, one of the foremost exponents, in a paper only a few months old. "In my opinion the Universe itself is only an hypothesis. Our observations cover only a very limited part of space and time which I have been in the habit of calling 'our neighbourhood.' The 'Universe' is a hypothetical concept arrived at by extrapolation, beyond this neighbourhood. A complete theory of the Universe is not possible without hypotheses and we must be prepared in the theory of the Universe to meet with paradoxical results." The difficulty with many mathematical treatments of this and other subjects is that the assumptions and simplifications necessary are not sufficiently stressed, giving the end results a fictitious reality

they by no means possess, so that the present views of the Universe are certainly not final, and will probably be much modified.

Einstein's relativity Universe assumed that there were no general preponderating motions, the Universe was static. The galaxies were supposed to be uniformly distributed and the density of space uniform. The general equations of relativity give a relation between the density and the so-called radius R of the Universe. Einstein, however, found it necessary to introduce into the equations a certain unknown and mysterious cosmical constant, λ. This constant has a relation to the curvature of space-time; $1/R^2$, in Einstein's Universe is equal to it and must be a very small quantity. It was introduced by Einstein arbitrarily, a mathematical device to prevent the impossible contingency of the pressure in the Universe from becoming negative. As Einstein's model is static it offers no explanation of the apparent recession of the nebulae, although it has been used as the basis of some of the recent expanding models.

De Sitter's model of the Universe, on the other hand, ignores entirely the existence of contained matter or galaxies and has zero density, hence is quite different from reality. In this model the Radius R is connected with the cosmical constant by the relation $\lambda = 3/R^2$ which indicates its infinitesimal magnitude as E is usually defined in units of a thousand million light years. De Sitter found that the equations indicated that there would be produced in this Universe by the slowing down of atomic vibrations a red shift of the spectral lines of distant nebulae indicating an apparent recession. The difficulty lies in the emptiness of de Sitter's Universe where the introduction of matter or galaxies would distort the resultant form of the equations and the model cannot therefore account for both the red shift and the presence of matter in space. It has been shortly said that Einstein's world contains matter and no motion and de Sitter's motion and no matter.

These two models of the Universe did not, however, create much discussion among astronomers as there was considerable uncertainty in 1917 in regard to the structure and dimensions of our stellar system and the function of the spiral and other nebulae outside the galaxy. There were two schools of thought, one headed by Shapley, which made our galaxy several times larger than previously supposed with the spirals subsidiary, while the other

by Curtis considered the spiral nebulae as separate stellar systems. As you probably know the latter school has prevailed and our galaxy, though possibly larger than any other known, is now considered as but one among countless other stellar systems in the Universe. Indeed the most recent work on the absorption of light in our system, which appeared in the press only about a month ago, tends to reduce the estimated dimensions of the galaxy to the same order as those of the larger spirals. E. P. Hubble of the Mt. Wilson Observatory, is mainly responsible for settling the status of the extra-galactic nebulae, of which we can see some examples on the screen. He was able to resolve by the 100-inch telescope several of the spiral nebulae into stars and to show from the brightness of certain variable and other stars in these nebulae that they were individual stellar systems separated from one another by distances of the order of a million light years. These distances with the estimated masses enabled an estimate to be made of the density of space which had the incredibly small density of 1.5×10^{-31}gm/cm^3, which is about equivalent to one pound of matter in a cube of space a million miles a side. Using Einstein's model and equations of the space-time world Hubble gave the radius of the Universe as about 90,000,000,000 light years. As we shall see later, however, the dimensions given to the present supposedly expanding Universe are considerably more modest.

Shortly after the controversy on the status of the spiral nebulae and long before Hubble's work on the distances of these objects, Dr. V. M. Slipher of the Lowell Observatory with a spectroscope provided with a very short focus camera to shorten the exposures on these very faint objects, began to photograph the spectra of the brightest of the nebulae. He soon published the astonishing fact that the spectral lines in these nebulae were in general displaced markedly towards the red end of the spectrum. This displacement was several times greater than any observed in the stars, so that although astronomers would immediately agree that a red shift in the stars meant motion away from us with speeds on the average of about 20 km., 12 miles per second, the red shifts in the nebulae corresponded to speeds of the order of 1000 km/sec., and were so great as to lead to doubts whether this displacement might not be due to some other cause than the motions of the nebulae which if real were so great as to violate the

dynamical motions then prevalent. This splendid pioneer work was continued by Slipher until he had obtained what might best be called the apparent velocities of 41 of the brightest of the extra-galactic nebulae. In 36 of these, the line displacements were to the red, in one of them corresponding to an apparent velocity of recession of 1800 km., 1,100 miles per sec., while in 5 nebulae the lines were displaced to the violet by smaller amounts up to some 200 km./sec. This is now probably explained as due to the rotation of the galaxy sweeping the sun towards these nebulae faster than their outward motion, thus making the red shift of the nebulae general. Slipher's work in this and other pioneer fields has just been fittingly recognized, I am very pleased to say, by the award to him this year of the Gold Medal of the Royal Astronomical Society.

This surprising phenomenon of the apparent rapid recession of the nebulae, apparently all running away from our stellar system as if it were a plague spot, caused however scarcely a flutter in astronomical or relativistic circles. The red shift of some of the nebulae has been known for at least as long as the Einstein and de Sitter models of the Universe and the whole 36 nebular red shifts by 1922, but neither they nor any other relativist thought apparently of applying this phenomenon to the space-time world. De Sitter does say in discussing his empty universe that the properties of his space-time model would slow down atomic vibrations and would hence displace the spectral lines to the red, giving a spurious effect of recession, but as his equations only hold for an empty world with no galaxies present, the matter went no further. There was an attempt by Friedman in 1922 to consider mathematically the relativistic equations for a Universe with motion, a non-static world, but as he did not attempt any application of his results, they attracted little attention. The effective pioneer of the non-static model was the Abbé Lemaitre of Louvain in 1927, who developed the idea that the red shift can be interpreted as due to the expansion of the Universe. Unfortunately this important paper was buried in a little read publication and entirely escaped attention.

So far then as astronomers and relativists generally were concerned the question of the space-time world remained exactly where Einstein and de Sitter left it in 1917 even though by 1922

Slipher's work on the nebulae had shown that 36 out of 41 had large red shifts corresponding to apparent recessional velocities up to 1800 km/sec. What really started the new phase of the expanding Universe which has created such commotion and confusion in scientific circles was another paper by Hubble in the Proceedings of the National Academy of Science in the spring of 1929, less than four years ago. Hubble after his first work on the nebulae already referred to had developed further methods of obtaining estimates of the distances of these objects.

Altogether there were then available to Hubble the apparent velocities of 46 nebulae, the 41 by Slipher and 5 additional obtained at Mt. Wilson. Hubble obtained by various methods fairly reliable estimates of the distances of 24 of these nebulae which varied from about 100,000 to over 6,000,000 light years, of which the corresponding apparent velocities varied from an approach of 200 km./sec. to a recession of 1000 km/sec. A well-known method of analyzing cosmic velocities enables the motion of the sun with respect to any group of objects to be obtained. This when applied to the naked eye stars shows that the sun is moving towards Lyra with a speed of 20 km/sec. As Hubble saw from the tabulation of distances and velocities that there was an increase of velocity with distance he added a term in the equations to meet this condition and found that with respect to the nebulae the sun appeared to be moving towards Cygnus, not far from Lyra, with a speed of 280 km/sec., while the increase of apparent nebular velocity with distance was about 500 km/sec. per million parsecs, per 3,260,000 light years, a parsec being 3.26 light years and hence corresponding to 100 miles per second per million light years. We now believe that the solar velocity of 280 km/sec. is mainly due to the rotation of the galaxy, the 20 km/sec. with respect to the naked eye stars being its random motion within the galaxy itself. When this 280 km/sec. is removed from the nebular velocities, the motions of approach either vanish or are much reduced and the residual apparent velocities when plotted against distances as seen in the slide show that the velocity increases linearly with distance.

This discovery of the velocity-distance relation with its important reactions on our ideas of the Universe to be discussed presently, led observationally to further intensive spectroscopic study at Mt. Wilson by Hubble and Humason with a special spectrograph

of very low dispersion having a camera lens of 40 mm aperture and 25 mm focus, f 0.6. The appearance of nebular spectra made with this instrument are shown in the slide which magnifies them about a thousand diameters, the original length of those made with one prism being only 1/20th inch. The spectra of the vast majority of the nebulae are very like the spectrum of our sum or of an average star, they are of course composite, a blend of the light from the stars of the nebulae. The most noticeable features are the H and K lines of calcium whose normal position is shown in the upper spectrum. Comparing these with the lines in the lower spectra you will observe they are shifted further and further to the right or red end corresponding to apparent velocities of 185 km/sec. of approach and 4,900, 6,700 and 19,700 km/sec (12,000 miles/sec.) of recession. There is practically universal belief among astronomers that these displacements and the corresponding apparent velocities are substantially correct, that if the red shift is a real motion of the nebulae, by no means yet established, they are receding with these almost unbelievable speeds.

The estimates of distance are much more uncertain, however, although probably of the right relative order. Most of the 50 nebular spectra made at Mt. Wilson in the last three or four years are of the brightest nebulae in groups or clusters of nebulae for which the distances can be estimated more reliably than those of individual nebulae. When these distances are plotted against the apparent velocities, we have an extension of the velocity-distance relation as seen in the next slide, the data of the first curve being shown at the extreme left. The greatest apparent velocity yet published is of a very faint nebula in Gemini of some 24,000 km, 15,000 miles per second which has an estimated distance of 135,000,000 light years. These more recent measures which are about at the limit of observation with the 100-inch telescope give a corrected velocity-distance relation of 560 km/sec. for every million parsecs and fully confirm the earlier work.

This remarkable relation that the displacement of the lines of the extra-galactic nebulae is proportional to their distances now seems established beyond reasonable question and admits of two fairly obvious explanations, Either this increasing red shift is a Doppler effect and the Universe, although it would be safer to say the part of it we can observe, is expanding at an alarming

rate, or else the displacement is due to some action on the light producing atoms which decreases their vibration frequency, hence increasing the wave length and shifting the lines to the red, proportionally to the distance of the source. It must be remembered that there is no known means of determining from the nebular spectra which of these two processes is operative, as the effects observable in the two cases are identical, and we must hence examine which is the more probable by other criteria. It seems undoubted, however, that either explanation must involve relativistic mechanics and the properties of the four-dimensional space-time world.

When the observational relation was first put forward definitely by Hubble in 1929, the general trend of the tentative explanations advanced suggested some mysterious process operating in the space-time world, slowing the atomic clock and thus producing the red-shift. I was present at the meeting of the Pacific Division A.A.A.S. at Berkeley in June, 1929, probably the first scientific meeting after Hubble's announcement of the velocity-distance relation, when no one appeared to have the temerity to suggest that the apparent velocities of some 5,000 km/sec. obtained by that time could possibly represent an actual recession of the nebulae.

Two hypotheses, suggesting that the observed red-shift is due to a decrease in light-frequency proportional to the distance have been advanced. Zwicky in 1929 considered several possible causes, other than velocity, of the red-shift of the nebular lines and advanced as a possible explanation a "gravitational drag of light." A light quantum in its long journey through space will pass other matter and will not only be deflected, just as star light is at a total eclipse, but will transfer momentum and energy to this matter. During this process the light-quantum will lose its energy and its frequency will be reduced causing the red-shift. Zwicky computed the possible effect which will obviously depend on the distance and the amount of matter, or the density of space, and obtained results of the same order as observed. The second hypothesis was advanced by MacMillan of Chicago in a letter to Nature a year ago, where he suggests that the red-shift is due to the loss of energy by the photon in its long journey of millions of years. This loss may be due either to inherent instability of the

photon, or possibly to collision with other photons and would result in a decline in frequency and hence a red-shift. MacMillan calculates a loss of one per cent in energy and frequency in 5,400,000 parsecs about equivalent to the observed red-shift. MacMillan is a well-known advocate of a very extended time-scale of millions of millions of years for stellar-evolution which will naturally make him object to the niggardly interval of only ten thousand million years or so, allowed by the theory of the expansion of the Universe.

I am not competent to pass on the validity of the assumptions involved in these two hypotheses of the origin of the red-shift. I think it is obvious, however, in view of the many difficulties encountered with the expansion hypothesis, to be discussed later, that they are at least worth considering, and while we have no definite evidence that the frequency of the light quantum may be diminished proportionately in its passage through great distances, or near cosmic matter, the difficulties do not seem much greater than those encountered in the alternative theory of the expansion of the Universe.

Although mathematical papers appeared by Robertson and Tolman later in 1929 and 1930 on the question of an expanding Universe these did not attract much attention and the question was not brought forcibly to the attention of astronomers and scientists generally until 1930 in a paper by Eddington at the May meeting of the Royal Astronomical Society, at which I had also the good fortune to be present. This was the first time, to my knowledge, it had been directly and unambiguously stated that the red-shift was due to the expansion of the Universe. Even then it was not expressed orally so strongly as it appeared later in the published paper or as it was echoed afterward by the mathematical physicists. Eddington's paper may be safely said to have started the present vogue in models of the Universe and the end is certainly not yet as there has been considerable lack of agreement among the various exponents. I will attempt in the remainder of this paper to give a summary of the various views advanced by different authorities and to formulate the present status of the problem.

Eddington began working in 1929 with McVittie to examine whether Einstein's static spherical Universe was stable. It seems undoubted that this work was undertaken in the hope of finding an explanation of the red-shift in the nebulae and the recently

discovered velocity-distance relation of Hubble. Before proceeding very far, however, Lemaitre's 1927 paper was drawn to Eddington's attention and it was at once apparent to him, although not hitherto realized, that Einstein's spherical space-time world was unstable. Although Eddington's hope of contributing some definitely new results was thus forestalled, his investigation from the astronomical standpoint is remarkably important and may well be briefly summarised.

Eddington starts with considerations regarding the value of the cosmical constant λ, which is unknown except as a value can be assigned from astronomical data. Its value, however, is so small as to be negligible except in the largest-scale applications and is negligible, therefore, within the solar system or galaxy. Besides involving λ the form and size of space will depend upon the distribution and amount of the matter in the Universe. On the assumption that the matter is uniformly distributed, approximately true in the part of space observed, space will be spherical and if this Universe is assumed as static there is but one solution, Einstein's Universe. For such equilibrium, space must have a particular radius and contain a definite mass, determinate in terms of λ.

However, an infinite variety of solutions can be found representing spherical worlds not in equilibrium. While remaining spherical they expand or contract, the radius being a fraction of the time. One great advance in Eddington's treatment was to show that, even if the spherical world (Einstein's model) was in equilibrium, this was unstable and the slightest disturbance would start it expanding or contracting. Eddington specifically states that there is nothing in the theory to show whether the instability will take the form of expansion or contraction, nor to indicate the rate of change. So far as theory goes, then, it cannot be stated whether the Universe will expand or contract, nor whether such an effect could be observed at nebular distances or whether it might not require distances a million times or more greater. Expansion was chosen and its magnitude determined, only on account of its agreement with the presumed recession of the nebulae, a perfectly legitimate assumption provided that the red-shift of the nebular lines can be unambiguously ascribed to velocity. If due to any other cause the possibility of which was indicated earlier, then the thesis falls to the ground, and this should be distinctly remembered.

It will be of interest to give some of the numerical data obtained by Eddington on the basis of Hubble's and Humason's results of an increase in apparent velocity of 500 km/sec. for every million parsecs. This corresponds to about 1/2000 of the velocity of light for a distance of a million light-years. That is to say that at a distance of 2,000,000,000 light-years the recessional velocity will have equalled the velocity of light. What happens at greater distances, a necessary postulate of the theory of relativity being that no velocity can exceed that of light, I shall leave the relativist to decide. Eddington says in this connection that there is no contradiction in this as the separation corresponds not to dynamical motion but to inflation of space, but to my mind the distinction is a pretty subtle one. Hence the radius of space has expanded by one part in 2000 in the last million years, or the radius has doubled within geological time. This rapid expansion of the Universe is incongruous with the usually accepted time-scale of millions of millions of years for the evolution of stars. The original radius of space, the radius of the Einstein spherical world, depends upon estimates of the density of space and, on the assumption that the density is considerably less than 10^{-28}gm/cm^3 the initial radius is of the order of 1,200,000,000 light-years. Eddington states it cannot be calculated how long a period has elapsed from the disturbance of the Einstein equilibrium to the present, but from the time it reached 1.5 times its original radius until the present can scarcely be more than 10,000,000,000 years. The Universe is now doubling its radius every 1,400,000,000 years, and in 10,000,000,000 years the spiral nebulae will be 10 magnitudes fainter than at present. Evidently then, the construction of the 200-inch telescope must be speeded up if any advantage is to be gained and, as Eddington says, astronomers must count themselves fortunate that they are just in time to observe this interesting but evanescent feature of the sky. Finally his theory gives a value of the total mass of the Universe, which should be fairly trustworthy. Since the mass initially formed an Einstein Universe of radius 1,200,000,000 light-years, it is found to be $1.1\times10^{22}.=2.3\times10^{55}$ gram$=$ 1.4×10^{79} protons.

Eddington's work was the signal for other treatments of the non-static world, of which perhaps the most important was de Sitter's. De Sitter calculated the theoretical course of expansion

and contraction for a large number of models, assuming that the transformation of matter into radiation could be neglected. The general trend of his work can best be obtained non-technically by a quotation from a lecture to the Astronomical Society of the Pacific over a year ago,—

"The reason why we thought the Universe of Einstein and de Sitter the only ones was that fifteen years ago we were looking only for static solutions, taking it for granted that the Universe should be a stable structure. If we drop that assumption and think of the Universe as being in course of evolution from one state to another, then there are not only two possible solutions but an infinite number of them. The static Universe is one extreme having density and no expansion; the empty Universe having expansion and no density is the other extreme. Between these two extremes there is a whole family of solutions of intermediate type having both density and expansion. The actual Universe is one of this family, it started as a static Universe in the past and has since been expanding, until, after an infinite time, it will have reached a state very similar to the empty Universe."

Eddington has recently put forward a new and interesting development of such an expanding Universe, a determination of the rate of expansion not from measures of red-shift in the nebulae but from an interpretation of the wave-equation containing the mass m of an electron. Eddington says:

"Although theory predicts the phenomenon quantitatively it gives no hint of its scale. So far as relativity theory is concerned we do not know whether the recession will be perceptible within range of our telescopes . . . This is a weak point in the claim that the observed recession of the nebulae is actually the theoretically predicted expansion. The observed recession if accepted as genuine is alarmingly rapid, and the consequences in regard to the time-scale of stellar evolution are most startling. For this reason, there has been some disinclination to admit the genuineness of the velocities of the nebulae, and it is suggested that the red-shift of their light has some other explanation. Those who take this view need not dispute the theoretical prediction of an expanding Universe since the theory does not assert the expansion will be rapid enough to detect."

Eddington therefore attempted to relate theoretically the

cosmical constant λ, the radius, the mass, the density, the number of protons in the Universe and the magnitude of the velocity-distance relation, with the wave equations of atomic theory. The matter is highly technical and does not admit of any popular explanation but we may obtain some idea of his reasoning. Eddington states that our standard unit of length is an entirely arbitrary quantity, the yard or metre bar, whose length will depend upon the properties of the space in which it is measured or compared, in other words it depends on the curvature of space-time at the particular place and time. In determining the radius of the hydrogen atom for example it is much preferable, he says, to express this length in terms of the radius of curvature of space-time associated with that place and direction rather than with a variable yard or metre bar as the radius of the hydrogen atom is a constant fraction of the radius of curvature of the world. The constant λ is equal to $\frac{1}{R^2}$ where R is the radius of an Einstein Universe and Eddington concludes after involved reasoning that a term $\frac{\sqrt{N}}{R}$ where N is the number of protons in the Universe and R its radius should appear in the wave equation and should be equal to the term which is independent of the position of the mobile electron or $\frac{mc^2}{e^2}$. But $\frac{e^2}{mc^2}$ or b is considered as the conventional radius of the atom. Hence he obtains $\frac{\sqrt{N}}{R} = \frac{mc^2}{e^2}$ or $R = b\sqrt{N}$.

From these and another independent equation $\frac{GNm}{c^2} = \frac{\pi R}{2}$ he obtains theoretically the following dimensions of the original Einstein Universe before the expansion started.

R the radius of the Universe = 328,000,000 ps = 1,068,000,000 l.y.

M the mass of the Universe = 1.08×10^{-22}.

N the number of protons of the Universe = 1.29×10^{79}

ρ the density of space of the Universe = 1.05×10^{-27} gm/cm^3

The speed of recession of distant objects as calculated theoretically in this way from the wave equations and without any reference to observation comes out as 527.8 km/sec per million parsecs as compared with Hubble's first value of 500 and second of 560 km/sec. The value of the cosmical constant λ which as we have seen before

is equal $1/R^2$ becomes $\frac{9.8}{10^{55}\text{cm}^2}$. Eddington interpolates some remarks about λ which in view of more recent developments should be quoted and remembered. "The cosmical constant λ occurs in Einstein's law of gravitation. In the resulting equation of motion, the term represents a scattering force which tends to make all bodies recede from one another . . . This repulsion may be to some extent counterbalanced by the ordinary gravitational attraction of the nebulae on one another."

When the Universe has so far expanded that this gravitational attraction becomes negligible, the distances of the galaxies double themselves every 1,280,000,000 years. While it is not possible to give the present radius of the Universe it seems generally agreed that it is of the order of 10,000,000,000 light years, only one-ninth of the estimate reached by Hubble in 1926 from his determination of the density of space. According to Eddington's values above, for the density and radius of the initial or Einstein world, when it had expanded so that the density became Hubble's value of 1.5×10^{-31} gm/cm^3, the radius would increase about 25 times, thus giving the present radius as about 25,000,000,000 light-years. I believe that Hubble's density is too low so that our previous estimate of 10,000,000,000 light-years as the present radius of the closed and finite space-time Universe is as good as any.

Eddington concludes this remarkable paper with a characteristic word of caution. He says—"I do not want to stress too much the accuracy or finality of these results. I cannot see how anything can be possibly wrong with them, but then one never does see these faults until some new circumstances arise, or some ingenious person comes forward to show us how blind we have been." The fact remains, however, that it is a very beautiful original and complete piece of work and should be of special interest to astronomers as it gives us for example a theoretical method, independent of observations, of obtaining the much disputed position of the zero point in the period-luminosity curve of the Cepheids on which our knowledge of the dimensions of our galaxy and the distance of the others is so vitally dependent. I believe that Eddington's deductions of the relations of the space-time world to the wave theory of the atom have been by no means unreservedly accepted by relativists, but in addition there have been two serious attacks on

the basic foundations of Eddington's theory, two attacks on the reality of the cosmical constant and the curvature of space-time, by two redoubtable relativists Einstein and de Sitter, which, if valid, will entirely overthrow it.

Einstein in a recent paper before the Berlin Academy has pointed out that it is no longer necessary to retain the constant λ in the field equations. It was previously required in his static universe as without it the equations gave a negative pressure with a positive uniform density of matter, an impossible situation. If the Universe is not static, Einstein shows that there can be positive uniform density with zero pressure for zero values of λ, and he proposes, therefore to drop the λ term from the equations. As we have already seen Eddington states that the term λ represents the scattering force which tends to make the galaxies recede from one another and he counters Einstein by calling the latter's recent work an "incredibly retrograde step." While the two statements about λ may not be irreconcilable, there is certainly grave difficulty about this particular block of the foundations.

The second attack on Eddington's theoretical determination of the dimensions of the Universe appeared a few months ago in a paper by Einstein and de Sitter in the Proceedings of the National Academy of Sciences, which must have a serious reaction on all previous models of the space-time world, which have all assumed positive curvature of space-time. Einstein and de Sitter state that there is no direct observational evidence of the curvature, the only observed data being the mean density and the expansion. I may add that I doubt the possibility of any positive evidence on this matter as so far as we have observed up to 135,000,000 light-years there is no evidence that space is anything but the ordinary three-dimensional flat or Euclidean space we can all easily picture. The question then arose with Einstein and de Sitter whether it is possible to represent what is observed without introducing any curvature, another as essential building block of Eddington's theory as the constant λ which Einstein has already abandoned. They therefore proceeded to examine the effect on the field equations of assuming the curvature to be zero. The equations reduce to simple forms and the dimensions of space are readily calculated. Taking the velocity-distance relation as 500 km/sec. per million parsecs, Hubble's first determination, the density comes out with

zero curvature as $\rho = 4 \times 10^{-28}$ gm/cm^3. This corresponds to space in which all the galaxies are separated by a million light-years and each with masses of 200,000,000,000 suns. This is of the same order as generally assigned to our galaxy but the outside galaxies are generally believed to be very much smaller. They conclude "Although, therefore, the density corresponding to zero curvature and Hubble's rate of expansion may perhaps be on the high side, it is certainly of the correct magnitude and we must conclude that at the present time it is possible to represent the facts without assuming a curvature of three-dimensional space." As Eddington's theoretical work falls to the ground without positive curvature of space-time, you will have to ask someone but an astronomer what happens when the curvature is zero.

I had the privilege of hearing Eddington lecture on the Expanding Universe at the meeting of the International Astronomical Union at Harvard last September and was especially anxious to hear what he would say on this difficulty. However, he made no mention whatever of this paper of Einstein and de Sitter or of any difficulty in the matter. On approaching him afterward he told me that both Einstein and de Sitter, visiting England separately afterwards, had each assured him that it was the other one and not he who was keen on publishing the paper.

And these examples by no means exhaust the difficulties and contradictions occasioned by different assumptions and interpretations. Eddington and Tolman hold diametrically opposite views whether the transformation of matter into radiation will cause an expansion or a contradiction of the Universe, while McRae and McVittie on the one hand and Lemaitre on the other equally disagree on the effect of the formation of condensations in the change of dimensions of the Universe. But I think the wildest speculation of all is by the Abbé Lemaitre, who first developed the mathematical treatment of the expanding Universe. Lemaitre said at Pasadena last month—"I think all the matter in the Universe (I followed by 22 ciphers times that of the sun) was once condensed into a single primordial atom and that this atom exploded with such force that we still see some of the smoke going away. And ever since that original disintegration matter has been breaking up into lighter and simpler substances. We are still in time to see this wonder world for we still have radium which

has not completely extinguished into dull substances like helium and lead." If that is not an example of speculation run mad without a shred of evidence to support it, I miss my guess and such vagaries by a competent mathematician do not tend to increase confidence in other work along that line. Even Einstein is reported to have stated at the conclusion of Lemaitre's talk—"The most beautiful and satisfying explanation of the source of cosmic rays I have listened to."

This brings the expanding Universe up to date and it will be decidedly interesting to compare the views held five or ten years from now with those current to-day. I will be much surprised if there is not a radical change in the properties of the space-time model of the Universe.

Before closing mention should be made of an entirely different explanation by Professor Milne, who has done much valuable work on the interior constitution of the stars. Milne departs entirely from relativistic concepts to explain the recession of the nebulae and starts with the somewhat improbable assumption that the nebulae had originally velocities of all magnitudes from zero up to 20,000, 100,000 or more kilometres per second and in all directions at random. After a certain time they will obviously have sorted themselves out and all will be receding from us the ones further away going faster than the nearer ones exactly as Hubble had observed. This hypothesis does not require curved space or any of the peculiar properties of the relativistic Universe now holding the stage. Simple three-dimensional space suffices and we get rid of some of the paradoxical properties of the expanding model. We still, however, have the initial dynamical difficulty of what gave the tremendously massive galaxies such incredible velocities.

Amid such theoretical confusion, the observational astronomer, such as I, may happily restrict himself to the firm conviction that the displacement of the nebular lines to the red is approximately proportional to the distance without attempting to say that this displacement represents a motion of the bodies concerned. He may feel reasonably certain that space to the limits to which he can observe is Euclidean and he can safely leave the mathematicians to worry about the curvature of space-time.

REVIEW OF PUBLICATIONS

La Philosophie scientifique, par Hans Reichenbach, 43 p.

Structures et Propriétés optiques des Carbonates, par H. Brasseur, 29 p.

Les Bandes moléculaires dans les Spectres stellaires, par P. Swings, 29 p.

Sur la Théorie du Rayonnement, d'apres C. G. Darwin, par E. Néculéa, 24 p.

Sur l'Absorption exponentielle des Rayons Beta du Radium E, par G. Fournier et M. Guillot, 38 p.

La Recherche scientifique, par Jean Perrin, 24 p.

La Diffraction de la Lumière par de Ultra-sons, par L. Brillouin, 32 p.

L'Univers en Expansion, par Henri Mineur, 42 p.

Réel et Déterminisme dans la Physique quantique, par E. Meyerson, 48 p.

Les Théorèmes de Conservation dans la Théorie des Chocs électroniques, par L. Goldstein, 26 p.

The above pamphlets are included in the series "Actualités scientifiques et industrielles" published by Hermann, 6 Rue de la Sorbonne, Paris. In them the important problems of present-day physical science are discussed by outstanding scientists. The size is 6½ × 10 in., and prices are from 6 to 10 francs. These publications are recommended to any person who wishes to have an authoritative treatment of the subjects to be found in this series.

C. A. C.

Matière et Énergie par Victor Henri. 436 pages, 6 × 9½ in. Paris: Hermann, 1933. Price, 110 francs.

In this book Professor Henri has assembled the known facts concerning the structure of matter. Beginning with a discussion of the evidence relative to its continuous or discontinuous character, he

outlines the various experimental researches which have thrown light on its nature, and the way in which they have been interpreted. The questions treated are: methods of counting atoms or molecules, the definition of a chemical element, X-ray spectra, the classification of the elements, radioactivity, isotopes, the artificial disintegration and synthesis of elements, the kinetic theory of gases, and the structure of the atom, and the book is as up-to-date as is possible in a field in which work is being carried on so intensively at the present time. While the treatment is by no means what is ordinarily understood by "popular", a store of information is presented in a form in which it is readily available not only to advanced students but also to those whose knowledge of physics and chemistry is more elementary. No attempt is made at any time to give experimental details or a complete mathematical or theoretical treatment of the subjects deal with, but for those who may be interested the excellent bibliographical notes give ample indication of where these may be found. The numerous numerical tables included throughout are also worthy of note.

E. J. A.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

A Brilliant Fireball seen near Montreal.

Mr. John T. Farmer, of Montreal, gives the following observations of a fireball seen by him at the Canal Locks, Ste. Anne de Bellevue, on May 19, at 8.08 p.m. E.S.T.:

The object was first visible about 25° above the horizon in the N.W. Its course was inclined downward, and it faded out about 15° above the horizon a little south of due W. During the first half of its course it showed an intense white light, apparently many times as bright as Venus at her maximum. One man reported that he noticed the general illumination although he did not see the meteor itself. It gradually diminished to a reddish yellow. In the latter half of the course the meteor appeared to disintegrate rather irregularly, some of the fragments being thrown off and merging in the trail of light which, however, persisted for only a couple of seconds.

Another Case of Ball Lightning.

This phenomenon is so rare and so mysterious that it is desirable to collect all available information regarding it.

At about 11 p.m., May 1, the long L-shaped barn of Mr. William Swain of Stouffville, about 25 miles northeast of Toronto, was struck by lightning. The storm was observed from a window of the house some 150 yards away, and Mr. Swain gives the following description of it:

"The discharge appeared to be about the size of a football and much the same shape, with a purplish coloured streak up from it which got smaller near the top and seemed to end in a point at the top. It appeared to come straight down. It came fairly fast. It struck the east end of the barn and came down in the stable. The sound came almost with the flash, and was very loud. It seemed to strike very solid, jarring everything for miles around.

"The fire seemed to start instantly. We did not feel any shock ourselves and did not notice any smell.

"The first two cows inside the stable door were all right, the third one was dead, the fourth one seemed a little stunned, the fifth one seemed to have no use of her hind parts, but could use her foreshoulders and forelegs, the next two were all right.

"In five minutes after I saw the ball fall we could not get anything out of the barn and stable, which were a mass of flames."

AUDIBILITY OF THE AURORA.

Mr. A. L. Roberts, of 629 Belmont St., Montreal, under date May 29, writes:

"The aurora as seen by me at St. Denis St., in Montreal, which I described in a letter to Dr. A. Vibert Douglas of McGill University shortly after, agrees with the accounts given in the May-June issue of the JOURNAL.

"It was the sound that first drew my attention to the phenomenon. It was a quiet evening, not a soul in sight, not a sound of a car of any kind and no perceptible breeze. The aurora appeared to be of great extent in all directions but not very intense in luminosity; I could not say that it touched the ground, though it appeared to do so, but I could see no ray between myself and the buildings. I appeared to be in the centre of the zone, in the midst of a mighty hall, draped with luminous gossamer curtains which seemed to waft with some mysterious breeze.

"The sound was similar to a person moving about dressed in voluminous folds of taffeta-silk, faint but unmistakable. It had nothing to do with sound in the head. I am not subject to influence by fancy, besides I had already observed, on previous occasions, a number of distant effects. There is no doubt about the audibility of the aurora, but it is evident that one must be well within the affected zone to hear it."

Mr. Roberts suggests that observations of the aurora should be made from balloons or by means of an antenna connected to a suitable registering instrument. We may look forward to the auroral investigations now being made in the far north during this Polar Year. The present writer has learned that many pairs of photo-

graphs of auroral displays have been taken and from them the heights will be calculated.

How Young a Moon can be Seen?

Mr. E. G. Hogg, of the New Zealand Astronomical Society in "Astronomical Notes" for April, 1933, has some interesting information regarding the youngest moon which has been seen with the naked eye. I quote his remarks:

The new moon of November 28, 1932, was seen when its age was 17h 31min. This is not a record for South Africa, as the new moon of November 28, 1913, was seen there when it was only 16h 39min old.

Some chronological significance attaches to this phenomenon, as many ancient nations began their month with the first observation of the lunar crescent, and it is important to determine the shortest interval after new moon that they would be likely to see it.

In this context it is interesting to note that the older text books on astronomy give 31½ hours as the interval between the birth of the new moon and its first visibility with the naked eye. The Rev. S. J. Johnson, in his work on eclipses, gave 24 hours as the minimum age when the new moon may be visible in spring. Some years ago the late Mr. W. F. Denning reported an occasion when he had seen the new moon when only 20h 38min old, and quoted a case when the interval between the birth of the new moon and visibility had been only 18h 22min. Then the record seems to have stayed for some years until Mr. W. D. Horner reported that on February 10, 1910, when searching for a comet with a telescope, he saw the new moon when it was only 16 hours old; very careful scrutiny enabled him to pick it up with the naked eye, and his testimony was confirmed by three other observers.

The matter was fully investigated at the time, and calculation showed that the angular distance between the sun and the moon was only 10 deg 11½min, that the altitude of the moon above the horizon was 1 deg 47min, and that the broadest part of the illuminated crescent was less than 16 seconds of arc. It should be added that Mr. Horner's observation was made at a height of 485ft above sea level at a spot where the land sloped away to the westward, giving a clear horizon in that direction.

What the record is for New Zealand the present writer cannot say, but he commends the matter to the attention of observers as being one of interest and requiring no special instrumental facilities.

C. A. C.

MEETINGS OF THE SOCIETY

AT LONDON

March 10, 1933.—The meeting was held in the auditorium of the London Life Building, Mr. Gunn presiding.

Dr. Kingston introduced the speaker of the evening, Dr. D. B. Marsh, of Hamilton, whose subject was "Our Universe—its size, structure and what is beyond it." He showed by a drawing the shape of our galaxy whose longest diameter was said to be approximately 200,000 light years, with its centre somewhere between Ophiacus and Scorpio. The position of our solar system was shown. Photographs of star-clusters and different types of nebulae were shown, those of the spiral type being considered to be outside of our galaxy.

Rev. R. J. Bowen thanked the speaker on behalf of the Society and after questions and discussion the meeting was adjourned. There were fifty-two members and friends present.

April 13, 1933.—The April meeting was held in the London Life Building. Mr. Gunn, the president, introduced the speaker, Mr. F. H. Coates, whose subject was, "Astronomy, the Science of the Ages."

This science differs from others in that it is a study of elements far beyond the grasping fingers of man and those who would follow it do so from the pure love of the science. The beginning of the study of the stars is so remote that it may be said to coincide with the coming of man on the earth. The speaker pictured a cave-man sitting at the entrance to his dwelling at twilight and watching the twinkling lights appear in the heavens.

No records earlier than those of the Babylonians and Egyptians can be found. The curiosity of those ancient peoples was as great as ours, but through fear of the gods, they were withheld from prying into mysteries so beyond their reach.

"In ages past, the mystic raised
His pillared temples to the skies,
In awe of all unknown, he cringed
Before the elemental forces,
Whose mysteries he scarce dared look upon,
Save as deistic jealousies
Appeased by sacrifice.

To-day man dedicates to truth
The noblest temples man can plan,
Which rise with overarching domes
To house huge telescopes, which scan
The heavens to depths undreamed,
And send the plummet to infinity;
Exploring there to find at last
A finite universe without an end."

A picture of the Great Pyramid of Gizeh was shown which is believed by some to have been used for astronomical observations. There were many temples in Egypt dedicated to Ra the Sun-god. A picture of Stonehenge also was shown with its altar stone and the stone for marking the point of sunrise at the summer solstice. Ptolemy's geocentric system was touched on but not elaborated so the listeners were not put in the position of that King of Spain the speaker told of. When his tutor was demonstrating this intricate system of cycles and epicycles the king remarked, "If I had been there I could have given some profound advice." Adherence to this theory was maintained for fifteen centuries or more.

During the decline of the ancient civilizations of Egypt and Greece, political and religious upheavals caused the study of astronomy to degenerate into astrology and superstition. It, however, found a home in Arabia and observatories were erected in Persia in the eleventh century.

Tycho Brahe made possible the fixing of the position of planets and stars with such precision as to provide a foundation for the epoch-making work of Kepler and, later, of Newton. Then came the period of the first telescopes. The speaker showed pictures of what might be seen of the planet Saturn through these early telescopes side by side with one of the planet as we now know it. He then reviewed the astronomers since Galileo, telling what each has contributed to the science.

Since the birth of astrophysics in the beginning of last century the study of astronomy has made great progress.

May 12, 1933.—The regular meeting was held in the London Life Building, Mr. Gunn presiding. Three new members were elected:

Mrs. Dorothy Johnstone, Ontario St., London,
Captain Brown, London Airport,
Dr. Jno. A. MacMurchy, Dresden, Ont.

Rev. W. G. Colgrove was the speaker for the evening, and the subject was "The Moon".

He used as the basis of his address "A Summary of Interesting Items about the Moon", contributed by himself and published in the JOURNAL of November, 1930. Copies of this article were distributed among the members for reference.

The speaker used two ingenious devices to make clear the different move-

ments of the moon. One showed clearly the spiral paths of Mercury, Venus, the earth with the moon in attendance, Mars and Jupiter, correct for a period of nine earth-years. Questions and discussion followed the address.

N. MORRIS, *Secretary-Treasurer.*

AT TORONTO

March 14, 1933.—The regular meeting was held in the Physics Building of the University of Toronto, Mr. R. A. Gray in the chair.

Mr. Ernest L. Neill, 507 Robinson St., Cleburne, Texas, was elected to life membership in the Society.

The lecture of the evening was given by Prof. C. A. Chant on "The Precession of the Equinoxes." The lecturer, using a special globe, explained the meaning of such terms as the celestial pole, the celestial equator, the ecliptic and the pole of the ecliptic. The equinox is that point where the ecliptic cuts the celestial equator, and the angle between the two lines, which is, always approximately 23½° is called the obliquity of the ecliptic. The longitude of a star is measured from the equinox. Hipparchus, in the 2nd century B.C. found that the longitudes of stars were uniformly increasing in long intervals of time. He considered that the stars were fixed and that the equinox was slowly moving westward, as if advancing to meet the sun at each annual return. He therefore called this motion of the equinoxes "precession." Since the latitude of the stars are about constant, we therefore know that the postion of the ecliptic is fixed. Hence the precession of the equinoxes is due to a shift of the celestial equator. This means that the axis of the earth while maintaining a constant angle with the ecliptic, has a slow conical motion around the pole of the ecliptic. The celestial pole then moves in a circle at 23½° from the pole of the ecliptic, and the period has been calculated to be about 26,000 years. The celestial pole is now 1¼° from the star Polaris, which we call the north star. In 14000 A.D. the north star will be Vega. From the precession of the equinoxes the astronomer has been a help in determining the date of the Great Pyramid in Egypt to be about 2700 B.C. From a fixed position on the earth new groups of stars are becoming visible. In 13,000 years from now people living at Toronto will see the Southern Cross. We are also able to determine, by the names of the stars, that the earliest astronomers lived at about 3500 B.C. at a latitude of about 35°; possibly in Mesopotamia. Since the obliquity of the earth's axis to the ecliptic is constant, precession cannot cause any great change in our climate. The physical cause of the precession of the equinoxes was first explained by Newton. Since the earth is an oblate spheroid, the attraction of the sun and moon tends to draw the plane of the equator into coincidence with the plane of the ecliptic. But the earth is spinning, hence its axis makes a conical rotation, like the axis of an unsteady top. Prof Chant illustrated this by a spinning model of the earth.

March 28, 1933.—A regular meeting was held in the usual place. Mr. R. A. Gray was in the chair.

The following were elected to membership:

Miss Betty Adams, 519 East First St., Tucson, Arizona.

Mr. Gerald F. Spracklin, Windsor, Ontario.

Mr. H. D. Rothwell, 28 Glenholme Ave., Toronto.

Mr. Chas. D. McMaster, 50 Rose Ave., Toronto.

The address of the evening was given by Prof. Wm. Findlay, of McMaster University, on "Gravitation." Before the law of gravitation was discovered men were chiefly concerned with *how* bodies moved, and not *why* they moved. Galileo showed that the time required for a body to fall from the leaning tower of Pisa was independent of the weight of the body. Newton said that the force which pulls bodies to the earth should also account for the motions of the heavenly bodies; he calculated that the earth would pull the moon a distance of 13 feet in one minute, an amount equal to what had been measured. Thus he developed the law that every particle in the universe attracts every other particle with a certain force, the force of gravitation. Prof. Findlay gave several illustrations of Newton's law concering the motions of the sun, moon and the earth; it explains the precession of the equinoxes, and Kepler's three laws of motion of the planets. The most spectacular result of the law was the discovery of Neptune, and more recently of Pluto. Prof. Findlay then concluded with some of the wonders of gravitation: that it produces action at a distance: the attraction is independent of the physical properties as shape, size: it cannot be screened, it is not transmuted into any other force, and it acts instantaneously.

An able discussion of Saggitarius was given by Mr. Murray Stewart.

April 11, 1933.—A regular meeting was held in the usual place, at 8 p.m. Mr. R. A. Gray was in the chair.

Mr. T. H. Mason, 49 Maple Ave., Toronto, was elected to life membership.

The lecture of the evening was given by Dr. R. K. Young on "The Tides." The speaker explained that we have a distortion of the waters of the earth's surface caused by the sun and moon, and which we call tides. There is also a land tide, an air tide; and no doubt tides exist on other planets and between neighbouring stars. The tide-raising force can be calculated, using Newton's law of gravitation at any place on the earth. Assuming the surface to be all water, there would be a tide on the side of the earth adjacent to the moon, and a slightly less one on the side opposite to the moon; then as the earth rotates the effect would be to produce two high tides and two low tides in quadrature with them circulating east to west around the earth every 24 hours. But when the moon is at an angle of 28° from the equator, it will produce only one high tide at 60° latitude. Further complications arise when we consider the combined effect of the sun and moon in their varying positions, which produces four main tides of

different periods and amplitudes. The presence of land makes the problem still more complex. In a body of water of limited area when the moon "passes on," the wave started will become a free wave, the speed of which will then depend on the depth of the water, where the ocean is two miles deep, the velocity of a free wave is 500 miles per hour or about one half the speed of the moon. Therefore the tide lags behind the motion of the moon. The tide of the Pacific Ocean divides into two parts, one toward Cape Horn and the other westward, passing almost once around the southern hemisphere and reinforcing the former in the south Atlantic, and arriving in the north Atlantic when about two days old. One can predict the tidal components for a port, but not the magnitude or the time. There is much difficulty in measuring the tides in mid-ocean.

The lecture was illustrated with slides and drawings and many "tide expressions" were very clearly explained.

During the discussion that followed, Mr. William Gore described, using lantern slides, some tidal measurements which he had made on the west coast of England.

After a constellation study of Gemini by Mr. Hepburn, the meeting adjourned.

April 25, 1933.—The regular meeting was held at the University of Toronto at 8 p.m. Prof. C. A. Chant was in the chair. The following were elected members:

Joseph Broussard, Argo, Cook County, Illinois, U.S.A.,
C. N. Joyner, B.E., British Municipal Council,
Rev. John B. Lalime, S.J., 1855 East Rachel St., Montreal,
Rev. E. Cambron, S.J., Collège Ste. Marie, Montreal.

Mr. F. L. Troyer discussed the predictions of phenomena.

The Society was particularly favoured by having Sir Frederic Stupart address the meeting on "Recollections of Early Days at the Toronto Observatory."

In 1837 Baron von Humboldt discussed with the British Association for the Advancement of Science the proposal that a magnetic survey of the world should be started. The British Government agreed to institute, under army control, three observation stations for this purpose, one in S. Africa, one in St. Helena, and the third in Canada. Lieut. Riddell, who was in command of the Canadian contingent, located the magnetic observatory at Toronto, on the site where the McLennan Laboratory now stands. Lieut. Riddell began his observations in 1840, and was replaced by Capt. Lefroy in 1842. The observatory remained under military control until 1852, when it was turned over to the Government of Upper Canada, and was directed by Prof. Cherriman of the University of Toronto.

In 1856 the log building was replaced by one of stone, and Prof. Kingston became director. More meteorological work was now done, the high schools of the province were used as observing stations, and their reports telegraphed

to Toronto. Sir Frederic Stupart began his work with the observatory when Prof. Kingston was director. A fairly complete meteorological chart was produced as early as 1878. In 1871 Mr. Charles Carpmael joined the staff, and superintended the observation of the transit of Venus, 1882, using a six-inch telescope. Mr. Carpmael returned to England in 1894 and Sir Frederic Stupart was then made director of the Observatory. In 1907 the observatory was moved to make room for the physics building, and the old stone building now stands, practically unaltered, near Hart House. The work now became mostly meteorological, and Sir Frederic established many stations in all parts of Canada, particularly in the far north. He attended all the meteorological conferences in Europe, studied the methods of other countries and kept the Canadian system always to the front. In 1909 the observatory on Bloor St. was erected. Sir Frederic also told of his early impressions of Toronto, and of the beginning of the Astronomical Society, with Mr. Carpmael as first president.

At the close of the lecture, Mr. Andrew Thomson announced that Sir Frederic Stupart had been elected as Honorary Fellow of the Royal Meteorological Society of Great Britain.

G. HEPBURN, *Recorder*.

AT HAMILTON

March 14, 1933.—The regular monthly meeting was held in the lecture hall of the Public Library before a fairly large gathering.

On the motion of Mr. W. S. Mallory, seconded by Mr. T. H. Wingham, Mr. F. C. Foster was accepted as a member in the Society.

Mr. Mallory continued his series of short blackboard talks on the common stars to be seen in the heavens and encouraged his audience to look for these in the sky to learn their positions and appearance.

Mr. J. S. Taylor, of Richwood, gave a graphic description of the new moon and informed the members what they might expect to see on March 21.

Rev. D. B. Marsh, who had lectured in London the previous Friday, brought greetings and good wishes from the London centre.

Mr. Mallory introduced the speaker of the evening, Professor William Findlay, of McMaster University, who spoke on "Gravitation". He gave a most instructive address on the meaning, the laws, and the application of the laws of gravity and showed how these were applicable particularly to the science of astronomy and how the law of gravity co-ordinates and explains the character of many of the phenomena of astronomy.

April 11, 1933.—The regular meeting was held in the lecture hall of the Public Library, at 8.15.

The President, Mr. W. S. Mallory, made mention of the serious illness of Mr. F. C. Foster, a new member and an ardent supporter of the Centre.

A number of communications were received from American, English and

Canadian astronomers congratulating the eclipse party of the Centre on the results obtained by their observations and photographs during the solar eclipse of August, 1932, at Actonvale, Que.

Mr. Mallory gave his usual brief and instructive talk on the stars in the heavens.

In the unavoidable absence of Mr. J. A. Marsh, the address of the evening was given by Mr. T. H. Wingham, B.A.Sc. His subject was "Jupiter". Mr. Wingham explained the various theories of the origin of the planets, the Laplacian, the Planetesimal and the Theory of Tides. He described Jupiter's satellites and the various physical features of the planet, its appearance, density, etc.

J. A. LITTLE, *Secretary.*

AT VANCOUVER

April 11, 1933.—The sixteenth regular meeting was held at the University of British Columbia. Mr. Teasdale was in the chair.

In connection with programmes for future meetings, it was suggested that a course of lectures on general knowledge of the sky might be valuable.

Mr. H. C. B. Forsyth was appointed by the President as chairman of the telescope makers' group.

Rev. C. H. Shortt then gave a ten minute talk on the OBSERVERS' HANDBOOK and its use, the speaker being both witty and informative.

Two questions from the question-box were answered by Mr. Teasdale. These had reference to the shadow bands during an eclipse, and the cause of Baily's beads.

The subject for the evening was "Telescope Making" and was dealt with briefly by a series of speakers.

Mr. Bennett discussed the preparation of the mirror and the materials required. Commencing with a brief review of the object and theory of the astronomical telescope the speaker proceeded to describe the method of setting the grinding disk in pitch on top of a barrel, and the grinding process using No. 80 carborundum. For a six-inch mirror he recommended an 8-foot radius. After coarse grinding there follows a series of eight stages using successively finer carborundum.

Mr. Teasdale then described methods of polishing and testing. The polishing material is opticians' rouge which is held in pitch on the lower glass. After fifteen minutes of grinding the mirror should be tested, and in this connection the Foucault knife-edge test was described.

Mr. Forsyth continued with some remarks on figuring and silvering, in which he emphasized the difficulty of obtaining a perfect spherical surface and changing this to that of the parabola. Methods of mounting were briefly described. For silvering the speaker recommended the Brashear process, but also suggested the use of stainless steel for the mirror, a modification which he has found entirely satisfactory.

The meeting closed with a demonstration of the shadow test.

WILLIAM URE, *Recorder.*

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This Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

The Society has active Centres in Montreal, P.Q.; Ottawa, Toronto, Hamilton, and London, Ont.; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C.

The Society publishes a monthly JOURNAL containing each year about 500 pages and a yearly OBSERVER'S HANDBOOK of about 80 pages. Single copies of JOURNAL or HANDBOOK are 25 cents.

Membership is open to anyone interested in astronomy. Annual dues, $2.00; life membership, $25.00. Publications are free to members, or may be subscribed for separately. Apply to the General Secretary, 198 College St., Toronto, or to the local secretary of a Centre.

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General Index to the TRANSACTIONS of the R.A.S.C., 1890-1905, and the JOURNAL, Vols. 1 to 25, 1907-31.

Compiled by W. E. Harper, Assistant Director, Dominion Astrophysical Observatory, Victoria, B.C.

Pages, 122; Price, $1.00, postage 5c. extra.

New Materials for the History of Man—The Festival of the Dead, by R. G. Haliburton.

This is a research into the Year of the Pleiades, first published at Halifax, N.S., in 1863; reprinted by the R.A.S.C. in 1920.

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